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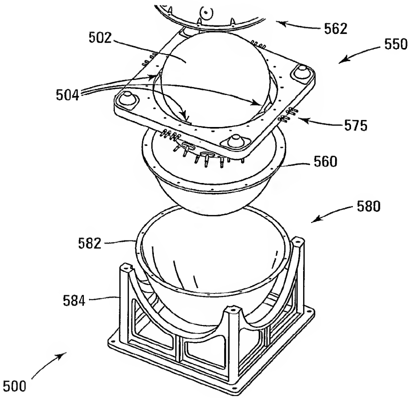
(54) Title: GAS JET CONTROL FOR INERTIAL MEASUREMENT UNIT



(57) Abstract: An inertial navigation system is provided. The system includes a gas supported sensor block that is adapted to rotate in three dimensions in a near frictionless environment, a plurality of jet plates adapted to receive two or more pairs of opposing pneumatic nozzles and a plurality of electronically controlled pneumatic valves that provides and controls gas to the opposing pair of pneumatic nozzles. Each pair of opposing pneumatic nozzles is directed at an exterior surface of the sensor block and uses gas flow to move and hold the sensor block in any rotational location without physically touching the sensor block.

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GAS JET CONTROL FOR INERTIAL MEASUREMENT UNIT

CROSS REFERENCE TO OTHER APPLICATIONS

This application is related to, and claims the benefit of the filing date of US Provisional Application No. 60/608,819, filed on September 10, 2004.

This application is related to co-pending United States patent application Honeywell docket number H0006540-1628, filed on even date herewith and entitled "GAS SUPPORTED INERTIAL SENSOR SYSTEM AND METHOD" (the '6540 Application). The '6540 Application is incorporated herein by reference.

This application is also related to the following applications filed on even date herewith, all of which are hereby incorporated herein by reference:

United States patent application Honeywell docket number H0007167-1628 (the '7167 Application), entitled "ABSOLUTE POSITION DETERMINATION OF AN OBJECT USING PATTERN RECOGNITION";

United States patent application Honeywell docket number H0007057-1628 (the '7057 Application), entitled "PRECISE, NO-CONTACT, POSITION SENSING USING IMAGING";

United States patent application Honeywell docket number H0007169-1628 (the '7169 Application), entitled "SPHERICAL POSITION MONITORING SYSTEM";

United States patent application Honeywell docket number H0007914-1628 (the '7914 Application), entitled "THREE DIMENSIONAL BALANCE ASSEMBLY";

United States patent application Honeywell docket number H0006475-1628 (the '6475 Application), "ARTICULATED GAS BEARING SUPPORT PADS";

United States patent application Honeywell docket number H0006345-1628 (the '6345 Application), entitled "RF WIRELESS COMMUNICATION FOR DEEPLY EMBEDDED AEROSPACE SYSTEMS"; and

United States patent application Honeywell docket number H0006368-1628 (the '6368 Application), entitled "GENERALIZED INERTIAL MEASUREMENT

ERROR REDUCTION THROUGH MULTIPLE AXIS ROTATION DURING FLIGHT".

TECHNICAL FIELD

The present invention generally relates to inertial measurement units and in particular to control of inertial measurement units.

BACKGROUND

Inertial navigation systems (INS) are used in civil and military aviation, missiles and other projectiles, submarines and space technology as well as a number of other vehicles. INSs measure the position and attitude of a vehicle by measuring the accelerations and rotations applied to the system's inertial frame. INSs are widely used because it refers to no real-world item beyond itself. It is therefore resistant to jamming and deception.

An INS may consist of an inertial measurement unit combined with control mechanisms, allowing the path of a vehicle to be controlled according to the position determined by the inertial navigation system. A typical INS uses a combination of accelerometers and any number of control devices.

INSs have typically used either gyrostablized platforms or 'strapdown' systems. The gyrostabilized system allows a vehicle's roll, pitch and yaw angles to be measured directly at the bearings of gimbals. One disadvantage of this scheme is that it employs multiple expensive precision mechanical parts. It also has moving parts that can wear out or jam, and is vulnerable to gimbal lock. In addition, for each degree of freedom another gimbal is required thus increasing the size and complexity of the INS.

INSs require periodic rotation to calibrate instruments. There is a need for rotational control of INSs without the use of conventional torque motors eliminating complex parts that add weight, size and cost to the INS assembly. A traditional method of rotating an INS for calibration is to torque it about an axis using electromagnetic motors on a ball bearing supported gimbal axis. A disadvantage of this method is that it employs multiple expensive precision mechanical parts. It also

has moving parts that can wear out or jam, and is vulnerable to gimbal lock. Another problem of this system is that for each degree of freedom another gimbal is required thus increasing the size of the inertial system.

Another type of inertial navigation system is one that floats a sensor assembly with neutral buoyancy in a fluid. This method requires an extremely complex assembly, sensitive temperature control and obvious sealing challenges that add considerably to the cost of deployment and maintenance. Also, many of these fluids are hazardous or require a high degree of purity.

For the reasons stated above and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for a guidance system which is inexpensive and easy to move in all directions without having parts that wear out or require extensive maintenance.

SUMMARY

An inertial navigation system is provided. The system includes a gas supported sensor block that is adapted to rotate in three dimensions in a near frictionless environment, a plurality of jet plates adapted to receive one or more pairs of opposing pneumatic nozzles and a plurality of electronically controlled pneumatic valves that provides and controls gas to the opposing pair of pneumatic nozzles. Each pair of opposing pneumatic nozzles is directed at an exterior surface of the sensor block and uses gas flow to move and hold the sensor block in any rotational location without physically touching the sensor block.

A gas jet control apparatus is provided. The apparatus includes three pairs of opposing pneumatic nozzles, wherein each of the three pairs of opposing pneumatic nozzles operates in axes orthogonal to each other. The three pairs of pneumatic nozzles receive gas from electronically controlled pneumatic valves. The gas is provided to rotate and hold an inertial measurement unit at any rotational angle without physically contacting the inertial measurement unit. The inertial measurement unit is floated in a near frictionless environment. The apparatus further includes a first jet plate adapted to receive two of the pairs of opposing pneumatic nozzles and a second jet plate adapted to receive a third pair of opposing

pairs of pneumatic nozzles

A method of controlling rotation of an inertial measurement unit is provided. The method includes floating an inertial measurement unit in a near frictionless environment, directing opposing pairs of pneumatic nozzles at an exterior surface of the inertial measurement unit in three orthogonal axis and driving gas through one or more of the opposing pairs of pneumatic nozzles and moving the inertial measurement unit in a desired manner within three dimensions.

DRAWINGS

Features and advantages of the present invention will become apparent to those skilled in the art from the following description with reference to the drawings, in which:

Figure 1A is a block diagram of one embodiment of a gas jet control system.

Figure 1B is a block diagram of one embodiment of a gas jet plate assembly.

Figure 1C is a block diagram of another embodiment of a gas jet plate assembly.

Figure 2 illustrates a cut away view of one embodiment of an inertial navigation system.

Figure 3 is a block diagram that illustrates another embodiment of a gas jet control system.

Figure 4A illustrates a mid-plate for an inertial navigation system.

Figure 4B is a block diagram of an embodiment of a gas jet plate assembly.

Figure 5 illustrates one embodiment of an inertial navigation system.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without

departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

Embodiments of the present invention provide a gas jet control assembly for an inertial measurement unit. This gas jet control assembly provides rotation necessary for high accuracy guidance systems when calibrating their instruments. The gas jet control assembly provides rotational control without the use of conventional torque motors by utilizing directed gas jets. The gas jets of the present invention are capable of controlling the angular position of a mulitaxis inertial measurement unit (IMU) without physically touching or being attached to any single axis of the IMU and can rotate the IMU in all directions. Embodiments of the present invention eliminate complex parts that add weight, size and cost to the IMUs. The reduction of these parts in turn increases the reliability of the system.

Figure 1A is a block diagram that illustrates one embodiment of a gas jet control system shown generally at 100. In this embodiment, a sensor block assembly 102 is rotated by gas streams from jet plate assemblies 104-1 and 104-2. Jet plate assemblies 104-1 to 104-2 use gas flow to rotate sensor block assembly 102 in three axes. In one embodiment, the gas used is nitrogen, air, or the like. In one embodiment, jet plate assembly 104-2 includes 2 pairs of opposing nozzles 105-1, 105-2 and 107-1 and 107-2, further illustrated in Figure 1C, with each pair of opposing nozzles 105 and 107 operating orthogonally to the other pair. For example in one embodiment, a first pair of opposing nozzles 105 operates in the x-axis and the second pair of opposing nozzles 107 operates in the y-axis wherein the x and y axis are orthogonal to each other. In this embodiment, jet plate assembly 104-2 includes 1 pair of opposing nozzles 103-1 and 103-2, further illustrated in Figure 1B, and operates in a third axis, z-axis, which is orthogonal to each of the other two axes, x and y.

Gas used by jet plate assemblies 104-1 to 104-R is turned on and off using valves 106. In one embodiment, valves 106 are electronically controlled pneumatic valves such as solenoid actuated pneumatic valves or the like.

Electrically controlled pneumatic valves 106 are controlled by a controller 108 that turns gas on and off to each nozzle 103-1, 103-2, 105-1, 105-2, 107-1, and 107-2 as needed for a given rotation command. In on embodiment, valves 106 pulse gas through jet plates 104-1 and 104-2. This allows sensor block 102 to be rotated

and held at any desired location in three axes.

Each nozzle of pairs of nozzles 103, 105, and 107 is aligned to allow air flowing through nozzles 103-1, 103-2, 105-1, 105-2, 107-1 and 107-2, and 107 to move sensor block 102 in a particular direction and an opposing nozzle of a pair of nozzles 103, 105 and 107 to move the sensor block 102 in the opposite direction. This allows movement of sensor block 102 in any rotational location in three dimensions and sensor block 102 to be arrested and held in place at any location.

Figure 2 illustrates a cut away view of one embodiment of an inertial navigation system shown generally at 200. Inertial navigation system 200 includes an inertial measurement unit or spherical sensor block 202 and an outer shell 204 that floats sensor block 202 in a near frictionless environment to allow motion in all directions. Embodiments of the inertial navigation system and spherical sensor block 202 are described in related application Honeywell Docket No. H0006540-1628 entitled "AIR SUPPORTED INERTIAL SENSOR ASSEMBLY" and filed on even date herewith.

In one embodiment, inertial navigation system 200 includes two or more jet plates assemblies 210. In one embodiment, jet plate assemblies 210 are as described with respect to jet plates 104 of Figures 1A-1C above. Due to the orientation of Figure 2 a second jet plate assembly, located about the equator of sensor block 202, is not visible but is a described above with respect to Figures 1A-1C. Jet plate assembly 210 includes 4 nozzles 212 that provide directional gas flow to rotate, stop, and hold spherical sensor block 202 into any rotational location. Due to the orientation of Figure 2 only nozzles 212-1, 212-2 and 212-3 are visible.

Inertial navigation system 200 further includes a plurality of valves 206. In one embodiment, valves 206 are electronically controlled pneumatic valves such as solenoid actuated pneumatic valves or the like. Valves 206 are controlled by a controller unit such as controller 108 described in Figure 1A above. Each nozzle 212 of jet plate assembly 210 is coupled to one or more valves 206. In operation, one or more of valves 206 provide pressurized gas to one or more nozzles 212 to rotate spherical sensor block 202. Nozzles 212 are angled to rotate sensor block assembly 202 in forward and reverse directions in opposing pairs in two orthogonal axes. The addition of another jet plate assembly such as 104-1 described with respect to Figure 1 above provides a third pair of opposing nozzles directed to rotate

sensor block 202 in a third orthogonal axis.

Each nozzle 212 is connected to an associated gas line 217. As discussed above due to the cut away illustration, only three of four gas lines 217-1, 217-2 and 217-3 are visible. Each of gas lines 217 are coupled to valves 206. In operation, valves 206 respond to control signals and regulate the gas to each nozzle to reposition senor block 202 and hold at precise angles.

Figure 3 is a block diagram that illustrates another embodiment of a gas jet control system shown generally at 300. Gas jet control system 300 includes a sensor block 302 and a plurality of jet plate assemblies 304-1 to 304-K coupled to a plurality of valves 306 coupled to a controller 308. In this embodiment, a sensor block assembly 302 is rotated by gas streams from jet plate assemblies 304-1 to 304-K. Jet plate assemblies 304-1 to 304-K use gas flow to rotate sensor block assembly 302 in three orthogonal axes. In one embodiment, the gas used is nitrogen, air, or the like. In one embodiment, each jet plate assembly 304 includes 2 pairs of opposing nozzles. For example jet plate assembly 304-1 includes a first pair of opposing nozzles 305-1 and 305-2 and a second pair of opposing nozzles 307-1 and 307-2 with each pair of opposing nozzles 305 and 307 operating to rotate sensor block 302 orthogonally to the resultant rotation caused by the other pair. A second jet plate assembly 304-2 includes 2 pairs of opposing nozzles 303-3, 303-4 and 307-3, 307-4. A third jet plate assembly 304-3 includes 2 pairs of opposing nozzles 307-7, 307-8 and 305-3, 305-4. A forth jet plate assembly 304-K includes 2 pairs of opposing nozzles 303-1, 303-2 and 307-5, 307-6. It is understood that any number of jet plate assemblies may be used to rotate, stop and hold sensor block 302 in any rotational location and the jet assemblies may be located at any location about sensor block 302.

Opposing pairs of nozzles 305 operate in the y axis. Opposing pair of nozzles 307 operate in the z axis. Opposing pairs of nozzles 303 operate in the x axis. Each axis is orthogonal to each other. As a result each opposing pairs of nozzles 303, 305, and 307 operate to rotate sensor block 302 orthogonally to each other.

In one embodiment, jet plate assemblies 304-1 to 304-K are as described above with respect to jet assembly 104-2 of Figures 1A and 1C.

Gas used by jet plate assemblies 304-1 to 304-K is turned on and off using one or more valves 306. In one embodiment, valves 306 are electronically controlled pneumatic valves such as solenoid actuated pneumatic valves or the like. Valves 306 are operated by a controller 308 that provides signals that control the amount and flow of gas via valves 306 to pulse gas through jet plates 304-1 to 304-K. This allows sensor block 302 to be rotated and held at any desired location in the three axes x, y, and z.

Each nozzle of pairs of nozzles 303, 305, and 307 is aligned to allow air flowing through nozzles 303-1 to 303-4, 305-1 to 305-4, and 307-1 to 307-6 to move sensor block 302 in a particular direction and opposing nozzles of a pair of nozzles 303, 305 and 307 to move sensor block 302 in the opposite direction. This allows movement of sensor block 302 in any rotational location in three dimensions and sensor block 302 to be arrested and held in place at any location.

In one embodiment gas jet assemblies 304-1 to 304-K surround sensor block 302 on the same plane with each gas jet assembly being comprised of four nozzles (two opposing pairs) angled toward the surface with each pair in opposing directions. This results in the use of 16 gas jets and provides for a great amount of torque and control of the rotation of the sensor block assembly.

Figure 4 illustrates a mid-plate for an inertial navigation system shown generally at 400. Mid-plate 400 includes a plurality of jet plate assemblies 404-1 to 404-M. Jet plate assemblies 404 are as described above with respect to jet plate assemblies 104 of Figures 1A-1C and jet plate assemblies 304 of Figure 3, or a combination of each. Each of the jet plate assemblies 404 includes one or more pairs of gas jets 451 as illustrated in Figure 4B. Each gas jet 451-1 to 451-4 is designed to receive a gas nozzle. The gas nozzles are not shown but are as discussed above with respect to Figures 1-3. Mid plate 400 fits around the exterior of a spherical sensor block, such as spherical sensor block of related application H0006540-1628, and gas plate assemblies 404-1 to 404-4, using the above described nozzles, direct gas at an exterior surface of spherical sensor block 402 to rotate and hold sensor block 402 into any desired location. It is understood that mid-plate 400 is designed to rotate, stop and hold any spherically shaped apparatus. Mid-plate 400 with gas plate assemblies 404-1 to 404-4 is calibrated to provide a designated amount of gas to rotate sensor block 302. The amount of gas, size of nozzle, shape

of nozzle, flow of gas (pulsed, steady or the like), the surface finish of the spherical apparatus are all factors used for design purposes. Figure 5 below illustrates an application of a mid-plate such as mid-plate 400.

Figure 5 illustrates one embodiment of an inertial navigation system (INS) shown generally at 500. INS 500 includes an inertial measurement unit or spherical sensor block 502 with a mid-plate 550 that rotates sensor block 502 into any rotational location. In one embodiment, mid-plate 550 is as described above with respect to mid-plate 400 of Figure 4. INS 500 further includes a first section 562 and a second section 560 that combine to form an outer shell for sensor block 502 that suspends sensor block 502 in a near frictionless environment. As described in related application H0006540-1628. INS 500 is supported by support structure 580 having a frame 584 and a base 582. Mid-plate 550 and first and second sections 560 and 562 are secured together and mounted on support structure 580 for stability.

Mid-plate 550 includes a plurality of gas plate assemblies 504. Only three gas plate assemblies 504 are visible in this illustration. A fourth gas plate assembly is employed and is located behind spherical sensor block 502. In one embodiment, gas plate assemblies 504 are as described above with respect to Figures 1 -4.

Each gas plate assembly 504 includes a plurality of gas nozzles as described above with respect to Figures 1-4. Sensor block 502 is floated by pressurized gas and is rotated by mid-plate 550.

In operation, the angular position of the sensor blocks described in Figures 1-5 above are controlled by angled gas nozzles. These gas nozzles are directed at the sensor block surface to impart tangential loads. A control system turns the nozzles on and off to reposition the sensor block and hold it at precise angles

In one embodiment gas nozzles are turned on and off using automated feedback control from a position sensor and feedback amplifier. In another embodiment, the gas is pulsed to control the rotation. Other ways such as having the gas always on and rotating the gas nozzles is contemplated and within the scope of the invention. In one embodiment, the gas nozzles include any combination of round, fan shapes, angled heads, spray heads or the like. The gas nozzles are made of any suitable material such as copper, steel, aluminum, plastic or the like.

In other embodiments, the amount of torque created on the sensor blocks

described in Figures 1-5 above, by the application of pressurized gas from gas nozzles, is controlled by the surface texture of a sensor block. Differing textures change the air friction coefficient for the sensor block such that a smoother surface texture results in less torque generated by the gas nozzles, while rougher surface textures result in more torque generated by the gas nozzles. In one embodiment, the sensor block surface is polished and smooth. In one embodiment, the sensor block surface is texturized. In one embodiment, the sensor block surface has a sandpaper texture. In one embodiment, the sensor block surface has the texture of 400 grit sandpaper. In one embodiment, a texturized surface is created from a reference pattern applied to the surface of the sensor block as described in the '7167 Application, herein incorporated by reference. To aid in the rotation of the sensor block, the amount of additional torque required from the application of a surface texture is a function of the size and weight of a sensor block, and the roughness of the surface texture, which one skilled in the art could readily determine.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

CLAIMS

What is claimed is:

1. An inertial navigation system (200), comprising:
a gas supported sensor block (202) that is adapted to rotate in three dimensions in a near frictionless environment;

a plurality of jet plates (210) adapted to receive up to two pairs of opposing pneumatic nozzles (212); and

a plurality of electronically controlled pneumatic valves (206) that provides and controls gas to the opposing pair of pneumatic nozzles (212);

wherein each pair of opposing pneumatic nozzles (212) is directed at an exterior surface of the sensor block (202) and uses gas flow to move and hold the sensor block (202) in any rotational location without physically touching the sensor block (202).

2. The system of claim 1, wherein the opposing pairs of pneumatic nozzles (212) operate in three orthogonal axes.

3. The system of claim 1, wherein the plurality of jet plates (210) is comprised of a first jet plate having two pairs of opposing nozzles (212) operating in two orthogonal axes.

4. The system of claim 3, wherein the plurality of jet plates (210) is further comprised of a second jet plate having a single pair of opposing nozzles (212) operating in a third axis orthogonal to the two orthogonal axes.

5. A gas jet control apparatus (100), comprising:
three pairs of opposing pneumatic nozzles (103, 105, 107) wherein each of the three pairs of opposing pneumatic nozzles (103, 105, 107) operates in axes orthogonal to each other;
wherein the three pairs of pneumatic nozzles (103, 105, 107) receive gas from electronically controlled pneumatic valves (106);
wherein the gas is provided to rotate and hold an inertial measurement unit (102) at

any rotational angle without physically contacting the inertial measurement unit (102);

wherein the inertial measurement unit (102) is floated in a near frictionless environment;

a first jet plate (104-2) adapted to receive two of the pairs of opposing pneumatic nozzles (105, 107); and

a second jet plate (104-1) adapted to receive a third pair of opposing pairs of pneumatic nozzles (103).

6. The apparatus of claim 5, wherein the gas jet control apparatus is a mid-plate (400) that operates around a circumference of the spherical inertial measurement unit (102).

7. A method of controlling rotation of an inertial measurement unit (202), the method comprising:

floating an inertial measurement unit (302) in a near frictionless environment;

directing opposing pairs of pneumatic nozzles (303, 305, 307) at an exterior surface of the inertial measurement unit (302) in three orthogonal axis; and

driving gas through one or more of the opposing pairs of pneumatic nozzles (303, 305, 307) and moving the inertial measurement unit (302) in a desired manner within three dimensions.

8. The method of claim 7, further comprising driving gas through one or more of the opposing pair of pneumatic nozzles (303, 305, 307) and moving the inertial measurement unit (302) based on one or more signals received from a controller (308).

9. The method of claim 7, further comprising holding the inertial measurement unit (302) in a specific location using gas flow through one or more of the opposing pairs of pneumatic nozzles (303, 305, 307).

10. The method of claim 8, wherein the one or more received signals indicate an amount and flow of gas to the opposing pairs of pneumatic nozzles (303, 305, 307) via electronically controlled pneumatic valves (306).

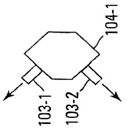


Fig. 1B

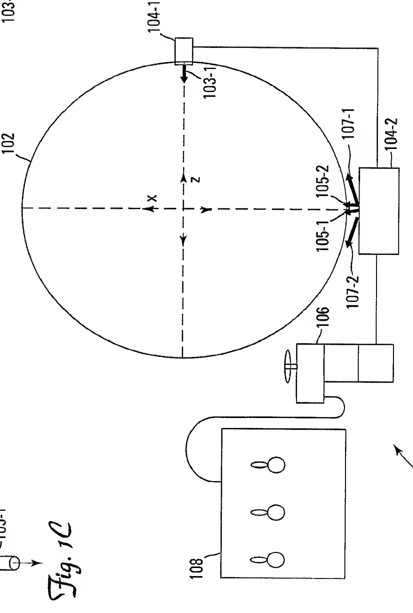


Fig. 1A

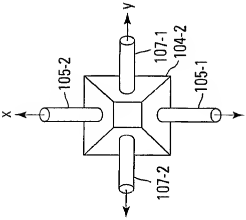


Fig. 1C

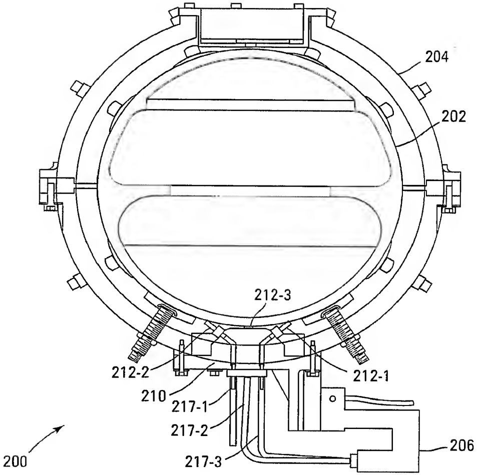
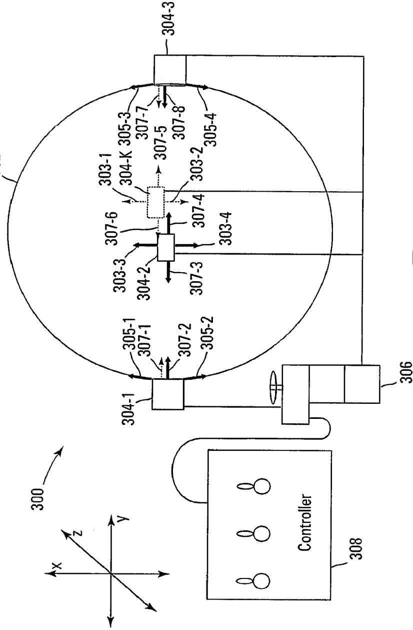


Fig. 2


300
302
303-1
303-2
303-3
303-4
304-1
304-2
304-3
304-K
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305-2
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305-4
306
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308
Controller
x
y
z

Fig. 3

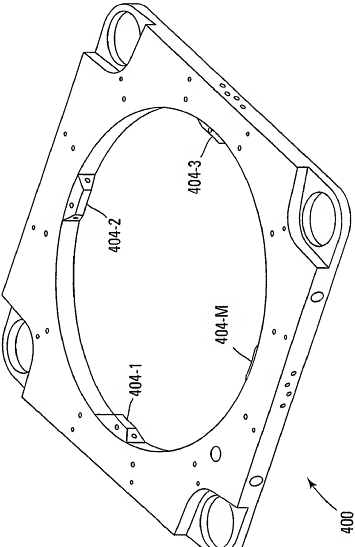

Fig. 4A

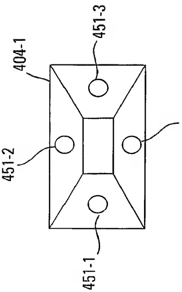

Fig. 4B

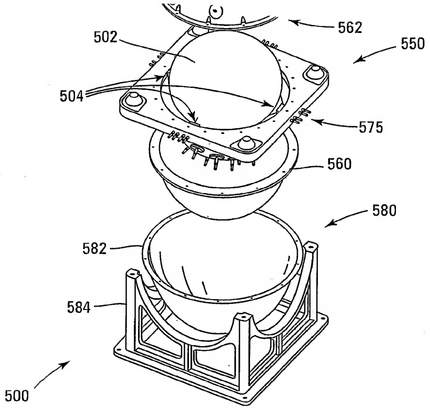

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2005/043534

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01C21/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	GB 866 473 A (THE ENGLISH ELECTRIC COMPANY LIMITED) 26 April 1961 (1961-04-26) figure 2 page 1, line 9 - line 56 page 2, line 13 - line 21 page 2, line 93 - line 126 claims 1,5	1-5,7-10 6
A	US 6 145 393 A (CANTON) 14 November 2000 (2000-11-14) figures 5-10 column 4, line 42 - line 51 column 6, line 15 - line 51 claims 1,9	1-10

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
13 April 2006	25/04/2006

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